Milking a rich education from an old school technique

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Key words: Education, EDM, logistics, communications

SUMMARY

Second year surveying students at UNSW are exposed to a lot of field work which becomes increasingly more complex as the year progresses. Most tasks are performed on campus for convenience and safety but the penultimate practical exercise in a term 3 course asks students to self-organise and plan their own logistics. GMAT2120 – Surveying and Geospatial Technology runs 6 separate field practical exercises focusing on digital levelling, total stations, leapfrog EDM height traversing and EDM distance measurement. The course culminates with a compulsory practical exam.

Long line EDM baseline measurement has been mostly replaced by GNSS rapid static or RTK techniques. However, to really understand deeply all the factors contributing to high precision distance measurement, a simple field practical has been devised, conveniently located on the beautiful Sydney coastline, just a few kms from UNSW main campus.

In lectures, students learn the theory of how an EDM works (both phase and pulse method), refractive index and the impact of atmospheric conditions on the length of a line. The practical exercise simply measures long lines (3, 6 and 9 km) between trigonometric stations located on the cliffs. All are intervisible. Students set their instruments to 0 ppm, measure temp/ pressure and apply corrections manually. They reduce their distances to the ellipsoid and project onto the grid and compare with the join derived from given state government coordinates. It is a simple task but so much learning can be derived from this one small exercise.

This paper seeks to deconstruct the various learning elements to encourage new and experienced surveying educators a fun way to engage students, provide a rich educational experience and a thoroughly enjoyable exercise as well.

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1. INTRODUCTION

GMAT2120 – Surveying and Geospatial Technology is a technical course delivered at the end of second year in the Bachelor of Engineering (Surveying) program at the University of New South Wales, Sydney. It has been adapted and modernised from Associate Professor Jean Rüeger's textbook Electronic Distance Measurement (Rüeger, 1996). 60% of the assessment in this course is based on field projects with 7 separate exercises.

Prac 1 – Intro to Digital Levelling/ Calibration and Rotating laser level	5%
Prac 2 – Precise Digital Levelling (second order)	10%
Prac 3 – Resection by direction/ Trig heighting	10%
Prac 4 – Total station exercises and tribrach calibrations	5%
Prac 5 – Leap frog EDM height traversing (second order)	10%
Prac 6 – EDM distance measurement	10%
Practical Exam	10%

Table 1: List of practical exercises.

The value of hands-on practical exercises to prepare students for a practical profession such as surveying is well recognised (Roberts & Harvey, 2019). Regular positive student feedback reinforces this assertion, however practical education is also a requirement for accreditation of 4-year surveying degrees leading to Registration/Licensing in Australia and New Zealand (Ibid, 2019, Nietschke, et al 2019).

All practicals are technical requiring students to provide a statistical analysis of their work, final coordinates or heights and an indication of the confidence level of these results. Indeed, good results are rewarded. Sufficiently precise student observations are combined into a large adjustment to improve the campus network. Students recognise that their work contributes.

From Table 1, the first 5 practical exercises and the practical exam take place on campus. Prac 6, the subject of this paper, takes place on the beautiful Sydney Sea cliffs at 4 intervisible trig stations (Roberts, 2021).

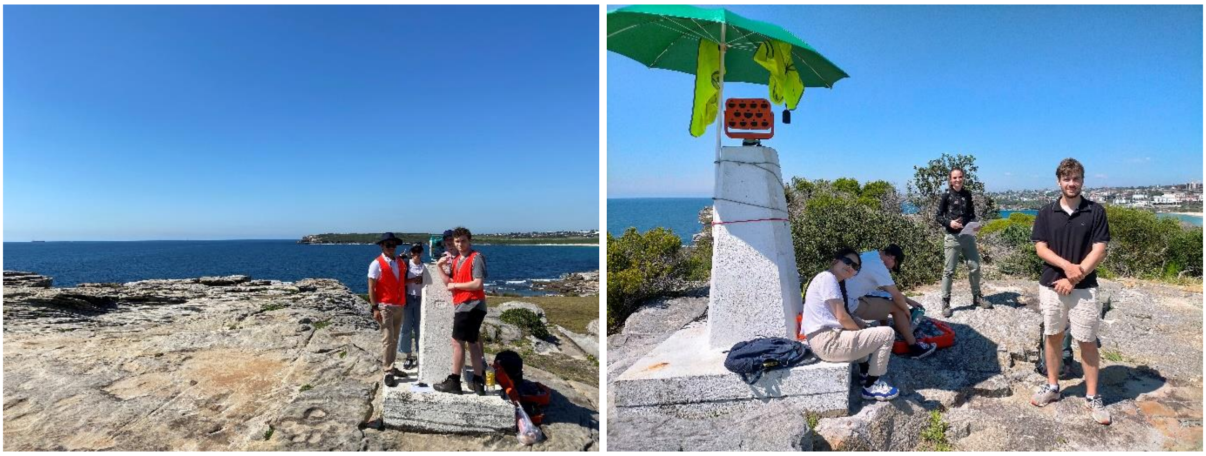

Figure 1 – EDM practical exercise on Sydney Sea Cliffs. Left: Students at Maroubra Trig, Right: North Bondi Trig

Practical exercises require creativity to design and develop, as well as energy and organisation to deliver, but the benefits are great. The EDM exercise was designed with longer lines primarily to exploit atmospheric errors and for students to experience the magnitude of a range of different errors. Rather than the software just reducing distances, this exercise provides the opportunity for students to return to first principles and understand each separate component and decide themselves which are significant or not.

2. THEORETICAL BACKGROUND

Preparatory lectures in this course provide a strong theoretical background for internal/external errors which affect surveying measurements in Digital Levels and Total Stations. In this last Electronic Distance Measurement (EDM) component of the course, students learn about the history and development of EDM from Geodimeters, microwave-based Tellurometers, mount-on EDMs to total stations, ultimately to reflectorless, robotic total stations and laser scanners. Students investigate the pulse and phase method of EDM and how these devices work. Parallels can be drawn with Global Navigation Satellite System (GNSS) devices.

Physical laws relating to EDM are introduced as well as the electromagnetic spectrum (EM) and the transmittance of waves through the atmosphere. This leads into the science behind phase refractive index and how this impacts distance measurement through the ambient atmosphere. The 1999 IAG resolution 3 on the group refractivity of standard air (N_g) (Equn 1) and for NIR in ambient conditions (N_L) (Equn 2) are presented (IAG 1999). Students begin to appreciate how science benefits the measurements of their reliable EDM devices. (λ is the wavelength of the carrier signal of the EDM instrument)

$$N_g = (n_g - 1)10^6 = 287.6155 + \frac{4.88660}{\lambda^2} + \frac{0.06800}{\lambda^4} \qquad \text{- Equn 1}$$

$$N_L = (n_L - 1)10^6 = (\frac{273.15}{1013.25}\frac{N_g P}{T}) - \frac{11.27e}{T}$$ - Equn 2

An error analysis of these formula reveals the well-known relationship to surveyors that for Near-Infrared (NIR) EDM, a change of temperature (T) of 1°C leads to 1 ppm error in distance. That is, if the thermometer is in error this propagates into the resultant distance. Similarly, a change of pressure (P) of 1mb leads to 0.3ppm.

Considering the humidity, the partial pressure of water vapour (e) is used, and students learn from error analysis that a change of 1mb propagates just 0.04ppm into a distance. It is negligible in most instances for NIR devices, yet using the refractive index for microwaves, the error is 4.6 ppm for a 1mb change in e. This is in large part why Tellurometers are no longer used for long line EDM measurements. But GNSS uses microwaves and this is why we consider tropospheric errors in GNSS positioning.

Students are then introduced to barometers and thermometers and are now a little wary about how accurately these devices might measure the t and p parameters (Equn 3) needed to correct EDM raw distances.

All this theory leads toward the introduction of the First Velocity correction K' (Equn 3).

$$K' = (C - \frac{Dp}{(273.15 + t)} + \frac{11.27e}{(273.15 + t)})10^{-6} d'$$ - Equn 3

Students learn that New South Wales (NSW) surveyors are required to calibrate their EDM devices over an approved calibration baseline every 12 months. When performing this task, they must set the standard temperature and pressure (colloquially referred to as "mets" - after meteorological measurements) in the EDM device to 0ppm and measure the mets to compute the first velocity correction externally (NSW Surveyor-General's Direction No. 5).

More theoretical background examines reduction of the first velocity corrected EDM distance to the ellipsoid (Fig. 2) and then projecting onto the grid (In Australia: Map Grid of Australia MGA2020).

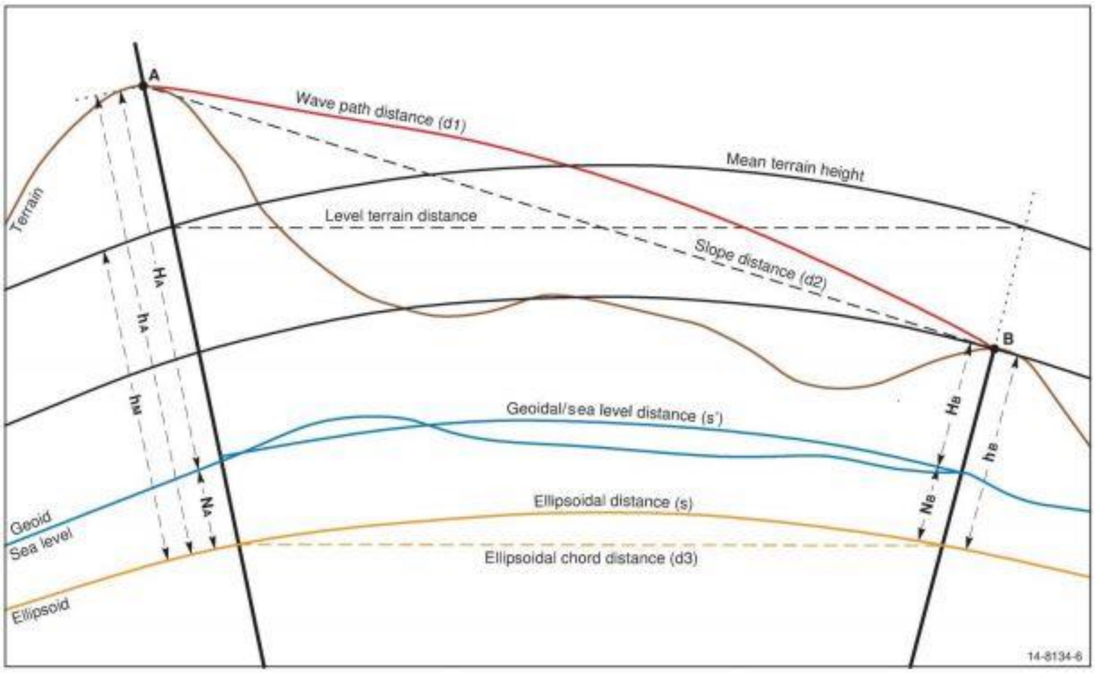

Figure 2 – Reduction of measured distances to the ellipsoid (ICSM 2022).

Students are instructed to carry out this reduction in a step-by-step method following the procedure detailed by Rüeger (1996). The first velocity corrected distance (d1 – Fig. 2) is reduced to the chord distance (d2). Next the so-called chord to chord correction is applied to reduce the distance to d3 the ellipsoidal chord distance. This is a combination of the slope correction and the sea level correction. Finally, the ellipsoidal distance (d4 or "s" in Fig. 2) is computed using a chord to arc correction. Computing each component individually, students learn to appreciate the relative magnitude of each step. They are also asked to recompute with a one-step formula (Ibid, 1996) and show that they achieve the exact same result.

In lectures, some time is spent explaining how to compute the radius of curvature of the Earth on the ellipsoid in the azimuthal direction of the distance being measured. This is an opportunity for students to compute how much the radius changes and appreciate the degree of flattening and how that affects the curvature on the ellipsoid – geometrical geodesy. Does this rigorously computed radius affect the distance reduction? That is for the students to investigate.

The next step in the computations is to project the ellipsoidal distance d4 onto the grid. Therefore, the scale factor needs to be computed. According to the GDA2020 Technical Manual (ICSM2022), surveyors can compute the point scale factor (PSF) or for longer lines, the line scale factor(LSF). Students are asked to compute the grid distance using the average PSF (derived from either end of the line) and compare with the grid distance derived from the LSF.

Because the measurements are taken to Trig stations with high quality, known coordinates, students are asked to compute the join from the known coordinates and compare this grid distance with their derived grid distance and comment.

It is important that sufficient theory is presented to scaffold the outcomes of this practical exercise during the reductions. Students are very much more engaged in the process when they themselves have stood in the wind and made the measurements themselves.

Figure 3 – Map of Trig stations. Note adjacent Trigs are approx. 3km apart.

3. LOGISTICS

The practical exercise itself is quite straightforward. Essentially students measure all combinations of long distances between each other with their EDM instruments set at 0 ppm and make all the reductions themselves to resolve a grid distance that can be compared with a known distance.

3.1 Checking meteorological instruments

As an optional task prior to the fieldwork, students can undertake a short mini-exercise together. Presumably the teachers running this activity will have multiple barometers and thermometers. Assemble all the devices and ask students to tabulate the current temperature and pressure for each instrument. Students can then see clearly how consistent all devices function and perhaps identify any unreliable equipment. The added benefit is that any student who is unsure how to measure the “mets” can learn now before the practical exercise commences in the field.

3.2 Logistics

Arranging transport to the site can take some effort. All Work, Health and Safety (WHS) documentation should be carefully prepared. Students volunteer to use their own vehicles as well as the university supplied vehicles. Not much gear is required for each team; An instrument with batteries, a set of prisms, field notes/ instructions, barometer/ thermometer, 10mm allen key to remove the Trig station cap and importantly a 2-way radio. Extra ancillary equipment can be included as required.

3.3 Experience

When students first arrive at their allocated Trig station, they need to remove the cap, set up their instrument and try to find the adjacent Trig station. For many of the students, this is the first time they have ever observed a distance of 3 or 6 or 9 kms. The problem of finding a distant target even with a telescope, dealing with sun or haze or wind can be a challenging first experience. The sense of how far their EM signal must propagate through the atmosphere becomes immediately more apparent to students.

3.4 Communications

Usually, the student groups head out into the field with no pre-determined plan. Questions such as; who will arrive first?, who should measure first?, which prism should be put up first and which way should it point?, are not confronted until students find themselves standing at their respective Trig stations. Hopefully they have previously agreed on a 2-way radio channel! Teachers allow students to make their own plans (and mistakes) and observe as they develop a procedure of which order to measure distances and how to work as a team. This is an excellent learning opportunity teaching communication skills, planning and teamwork.

3.5 Operations

Students are instructed to measure all combinations of distances by first setting the EDM to read 0 ppm (ie set standard mets in instrument) and booking 10 raw distance observations. Students can then see the spread of this set of distances and identify any outliers. They are asked to log the temperature and pressure before and after the observations at both ends of the line. Humidity from the local weather is used to derive the partial pressure of water vapour.

As a check, students input the ambient temperature and pressure and book a few extra distances. The difference between this atmosphere corrected distance and the 0 ppm distance immediately gives a sense of the magnitude of the first velocity correction.

When all combinations of all distances are measured and checked, the student groups simply pack up and return to the Survey Store at UNSW. The gear is returned and the teacher collates all the field notes, scans them and places on the education platform (Moodle at UNSW). Students are allocated an individual line (or lines) to compute. This is an individual assignment for submission.

4. MILKING THE EDUCATION

Before embarking on this practical exercise, it is important that students receive sufficient lecture material (2. Theoretical Background) and understand the intention of the task.

The mini-exercise comparing thermometers and barometers prior to the exercise is an opportunity to discuss the reliability of instruments. Do all instruments perform the same? Do all EDMs perform the same? What is the standard error listed in the technical specifications of the total station device that is being used? 2mm + 2ppm? What range can the device measure and in which atmospheric conditions? Students can be guided to consider this before heading out to the field in preparation. Do they expect that they can measure 9kms when the technical specifications only state 6km? These are all great opportunities for teachers to enrich the theory that has been presented and is about to be tested in the field.

Technical specifications also state the number of prisms required to achieve a certain range in certain conditions. Figure 1 (right) shows a bank of 11 prisms whereby individual prisms can be easily removed. Can a longer distance be achieved with fewer prisms? This can be tested in the field by progressively removing prisms and remeasuring. Fun and interesting.

As stated above, students learn logistics, communications and teamwork in the process of trying to coordinate the group (with two-way radios) to measure all lines successfully. There is often a chaotic start until the collective group agrees on a procedure to complete the task.

Sometimes conditions (sun, haze) preclude longer lines from being measured. This exercise usually takes about 3 hrs including travel time from UNSW campus.

The field work is relatively straight forward. The computations are more involved, and the instructions step the student through the required tasks (Table 2).

Task	Description of task
1	Compute mean values for p, t and d' (raw distance) (from field notes)
2	Compute the partial pressure of water vapour (e) using relative humidity from the weather forecast.
3	Compute the first velocity correction with and without (e)
4	Compare first velocity with diff derived from field measurement with ambient mets
5	Compute radius of curvature of Earth in azimuth of line (use grid brg for azimuth)
6	Compute arc - chord correction (d1 – d2)
7	Compute chord – chord correction (d2 – d3)
8	Compute chord – arc correction (d3 – d4)
9	Compute d1 – d4 in combined reduction formula and compare with step-by-step
10	Compute grid distance using line scale factor (LSF)
11	Compute grid distance using average point scale factor (PSF) and compare with LSF
12	Compute grid distance using combined scale factor (CSF)
13	Compute join using the known coordinates (trig stns) and compare with LSF and CSF

Table 2: List of computational tasks as set out in the practical instructions.

Assessment of these tasks is potentially cumbersome. Students are given a template (Table 3) to fill out as a summary of the tasks given in Table 2. This gives the student some extra guidance but also makes it significantly easier for teachers to mark and compare the results from different students on different lines.

Whilst there is considerable computation required in this assignment, most of the assessment for this exercise focusses on the comments and insights from students. The computations should be correct, but it is the interpretation of the computations that are most rewarded in this task.

Students are asked:

1) Comment (no more than a paragraph) on 1st velocity correction computed vs diff bet. raw distance with 0PPM and distance with entered mets.

2) Comment (no more than a paragraph) on magnitude of all corrections including scale factor

3) Comment (no more than a paragraph) on comparison of Line scale factor, average Point scale factor, combined scale factor and effect on grid distance
4) Comment (no more than a paragraph) on JOIN between known Trig marks and comparison with your reduced LSF grid distance. How close was it? Comments.
5) BRIEF Concluding remarks (critical appraisal of methods and results, discussion of success/failure + time spent in prep of report and feedback on improvements for prac)
6) Appendices (including field notes, computations (marks will be awarded for clarity of computations))

Item 1 checks that the first velocity corrections and the built-in instrument function accord.

Item 2 invites students to reflect on all their reduction computations to the ellipsoid, projection to the grid and notice which reductions were largest and gave the most impact.

Item 3 asks students to critically assess the various scale factor computations as a way of discerning which are important and when. Also, the number of significant figures required to distinguish a distance measurement to millimetre accuracy is exercised.

Item 4 has a fair amount of weighting attached. This question is searching for insight from the student. The closeness of the reduced result to the join calculation is less of a concern, rather why is the difference what it is? There are many considerations. When was the EDM last calibrated and how does this affect the comparison distance? What is the standard error of the instrument (2mm + 2ppm)? How long is the line? What is the temperature or pressure discrepancy at either end of the line and is it changing over time? What impact might this have? How good are the coordinates of the Trig stations? How can the surveyor know this? Any other insights.

Item 5 seeks to harvest any feedback from the students about the efficacy of the exercise and suggestions for improvements.

Item 6 is a space for students to list their calculations in long form for the teacher to check.

From a relatively simple distance measurement practical exercise, connections can be made to other courses in the program that cover physics, geodesy, statistics, surveying computations and survey management. It is hoped that the design of the assessment encourages students to reflect on their education thus far in the program.

Student:
Line: <Paris> - <London>
Instr. & S/N: <Sokkia S/N 130680>
Raw Dist Ave:
1st Velocity:
K' comparison*:
d_1:
K1:
d_2:
SCIMS Grid Brg:
R_α:
K23:
d_3:
K4:
d_4:
d_4 Closed solution:
LSF:
Grid distance LSF:
Ave PSF:
Grid distance Ave PSF:
Grid distance CSF:
SCIMS Join distance:
Diff Grid distance LSF – SCIMS(m):

Table 3: Template for student submission.

5. CONCLUDING REMARKS

This paper seeks to offer a handy guide for lecturers and teachers of surveying programs. The practical exercise is relatively easy to run using fairly standard equipment namely a total station or even stand-alone EDM. Best if several intervisible survey marks over medium lengths can be accessed. Using existing control within a state-based or national local geodetic network is encouraged, in part due to the reliability of the coordinates, but also to expose relatively junior students to network data used routinely by professional surveyors.

Whilst this exercise appears "old school" because long line EDM is not practiced often anymore with the advent of GNSS surveying, there are many very relevant elements that can be extracted from this exercise providing a rich educational tapestry for teachers.

Additionally, the fundamental lessons gained from this exercise are transferable to modern techniques.

It is hoped that after completing this exercise, that students will appreciate the complexity behind pressing a button and receiving a reduced result. Also, that students will be able to debug possible errors or misunderstandings with unusual results and will be able to quickly trouble shoot their survey practice.

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BIOGRAPHICAL NOTES

Craig Roberts bridges the gap between teaching and research, industry and academia of modern high technology precision geospatial technologies and its practical application. Expanding from a humble degree in Surveying, pioneering experiences in international field work using GPS for tectonic studies and a PhD in GPS volcano monitoring have ignited his passion for teaching and sharing expertise in this growing field. Current research interests; surveying education, datum modernisation, multi-GNSS, UAVs and laser scanning for high precision mapping.

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